The LHCb anomalies in the composite Higgs scenario

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Instant workshop on B meson anomalies
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based on E. Megías, GP, O. Pujolàs and M. Quirós arXiv:1608.02362
(see also arXiv:1705.04822)

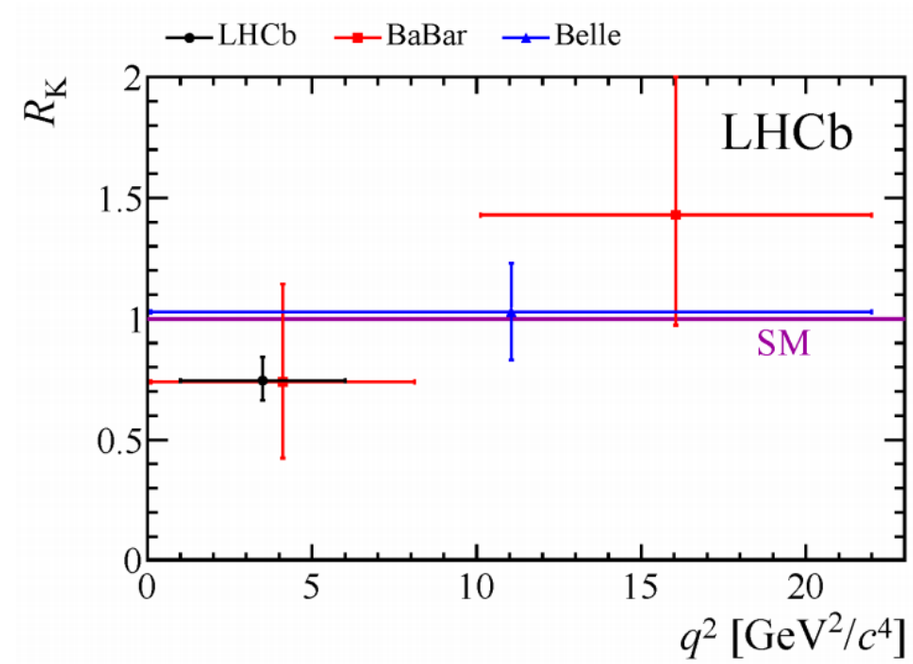
Hints of new physics in B decays

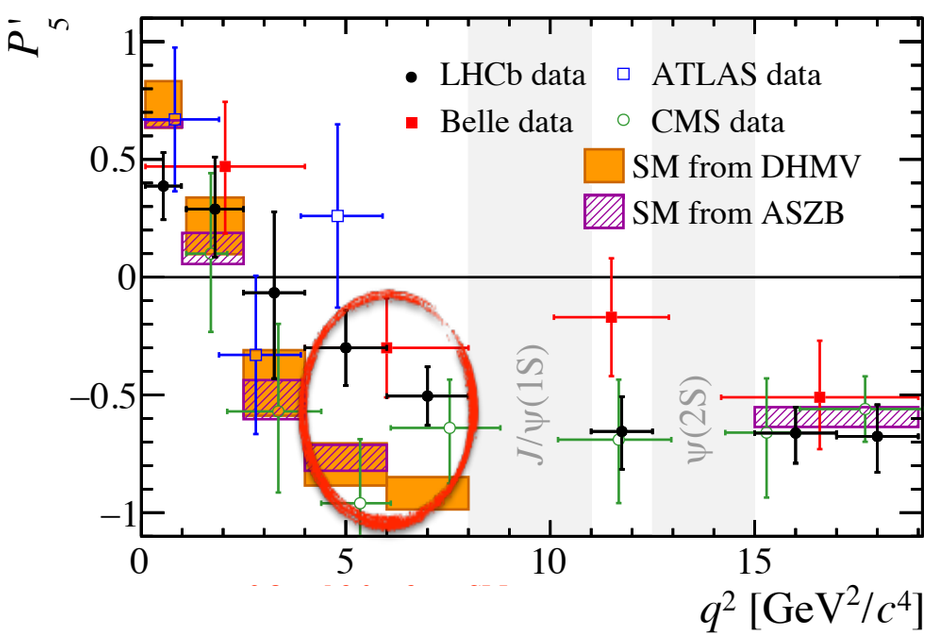
A coherent pattern of deviations in B-meson physics seems to emerge from the flavour measurements

- hints of **lepton universality violation** in clean observables R_K and R_{K^*}

$$R_K = \frac{\mathrm{BR}(B^+ \to K^+\mu^+\mu^-)}{\mathrm{BR}(B^+ \to K^+e^+e^-)} = 0.745^{+0.090}_{-0.074} \pm 0.036$$

$$R_{K^*} = \frac{\mathrm{BR}(B^+ \to K^*\mu^+\mu^-)}{\mathrm{BR}(B^+ \to K^*e^+e^-)} = \begin{cases} 0.660^{+0.110}_{-0.070} \pm 0.024 \\ 0.685^{+0.113}_{-0.069} \pm 0.047 \end{cases}$$



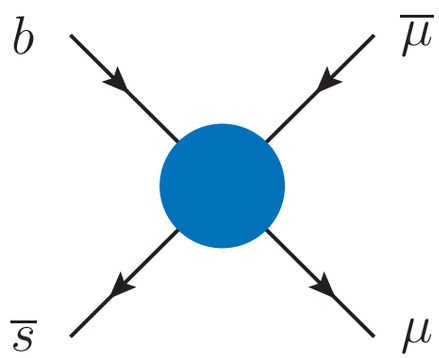


- additional deviations in other process related to the $b \to s\mu\mu$ transition

A simple pattern?

Compatibility with the data can be significantly improved if sizeable contributions to O_9 (possibly correlated to O_{10}) are present

[Capdevila et al. '17; D'Amico et al. '17; Altmannshofer et al. '17; Hiller et al. '17; Ciuchini et al. '17; Celis et al. '17; Geng et al. '17; …]



$$\left.\begin{aligned} \Delta C_9^\mu &\in [-1.43, -0.74] \\ \Delta C_9^\mu = -\Delta C_{10}^\mu &\in [-0.87, -0.36] \end{aligned}\right] \; 2\,\sigma \text{ intervals}$$

Many BSM models have been proposed to explain the anomalies

- leptoquarks [Kosnik '12, Hiller, Schmaltz '14; Sahoo, Mohanta '15; Becirevic, Fajfer, Kosnik '15; …]
- heavy Z' vectors [Altmannshofer et al '13; Gauld, Goertz, Haisch '13; Altmannshofer et al '14; Crivellin et al. '15; Sierra, Straub, Vicente '15; Celis, Fuentes-Martin, Jung, Serodio '15; Falkowski, Nardecchia, Ziegler '15; Descotes-Genon, Hofer, Matias, Virto '15; …]
- …

Looking for a bigger picture

Sizeable contributions are needed to reproduce the anomalies

generic feature of new physics: **new states with a mass ~TeV**

Could it be first hint of a bigger picture?

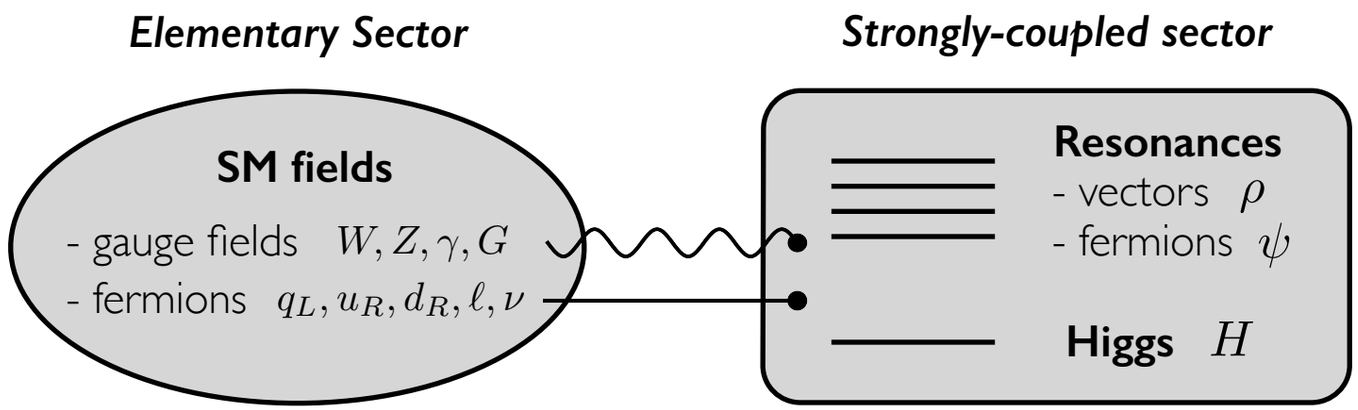
- intriguing possibility:

  relate the anomalies to the **Naturalness Problem**

- in this talk: explore this possibility in the context of scenarios with a **composite Higgs** and new stongly-coupled dynamics

Model-independent overview

Composite Higgs: General features



New strongly-coupled dynamics at a scale $\Lambda \sim \mathrm{TeV}$

✦ **composite** Higgs boson H

- EW scale naturally of order Λ ⟶ solution of the **Naturalness Problem**

✦ new **massive resonances** $m \sim \mathrm{TeV}$

- heavy vectors ρ (same quantum numbers as SM gauge fields)
- fermionic partners ψ (mixed with SM fermions: **partial compositeness**)

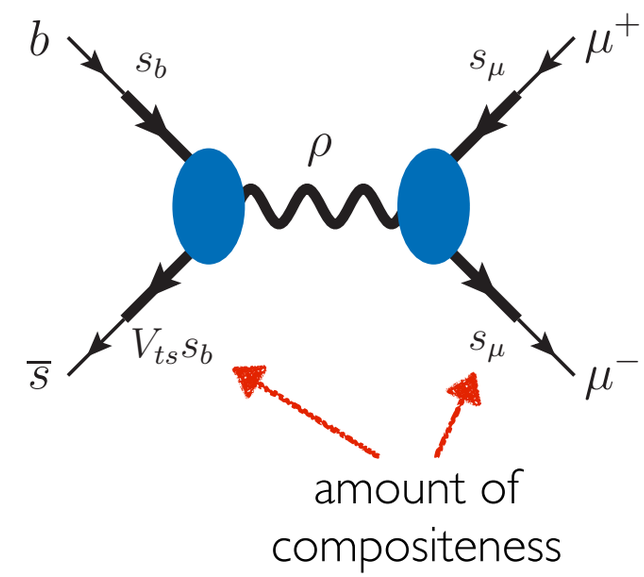
The $b \to s\ell\ell$ transition

see also [Niehoff, Strangl, Straub '15]

Vector resonances generate contributions to the O_9 and O_{10} operators

$$\Delta C_9^\mu \sim \Delta C_{10}^\mu \sim -\frac{\sqrt{2}\pi}{G_F \alpha_{em}} s_b^2 s_\mu^2 \left(\frac{g_\rho}{m_\rho}\right)^2$$

$$\simeq -0.4 \left(\frac{1\ \mathrm{TeV}}{m_\rho/g_\rho}\right)^2 \left(\frac{s_b}{0.3}\right)^2 \left(\frac{s_\mu}{0.3}\right)^2$$



- the B anomalies can be easily reproduced if the b and the μ have some amount of compositeness

$$s_b \sim s_\mu \sim 0.3 \qquad (m_\rho \sim few\ \mathrm{TeV}\,, \quad g_\rho \sim few)$$

  - electron almost elementary: **violation of lepton universality**

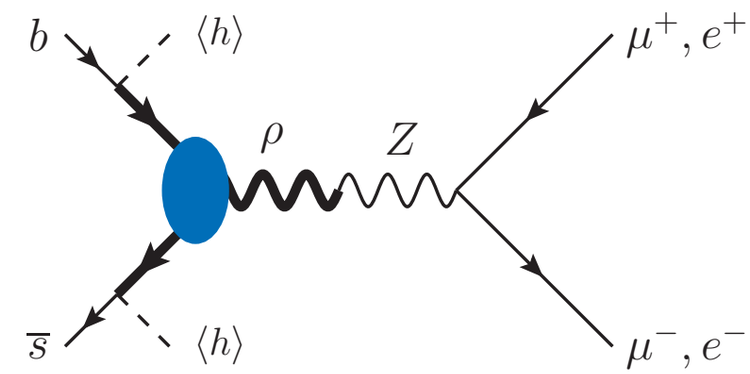
- preferred pattern: **left-handed compositeness**

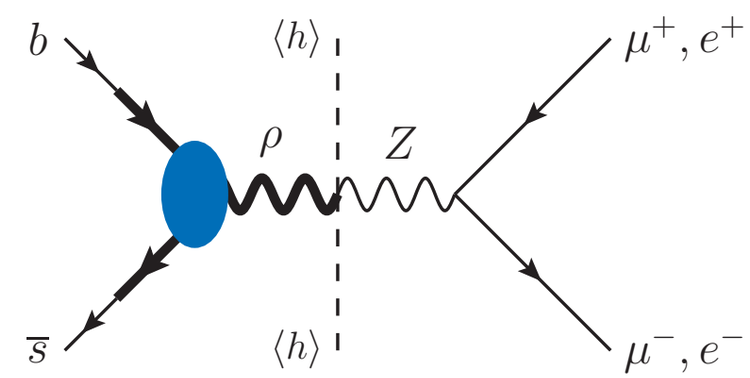
$$s_{b_L} \sim s_{\mu_L} \sim 0.3 \qquad s_{b_R} \sim s_{\mu_R} \ll 0.1 \quad \longrightarrow \quad \Delta C_9^\mu \simeq -\Delta C_{10}^\mu$$

The $b \to s\ell\ell$ transition

Additional effects from Z exchange

$$\Delta C_{10}^{e} = \Delta C_{10}^{\mu} \sim \frac{\sqrt{2}\pi}{G_F \alpha_{em}} s_{b_L}^2 \frac{g_\rho^2}{m_\rho^2}$$





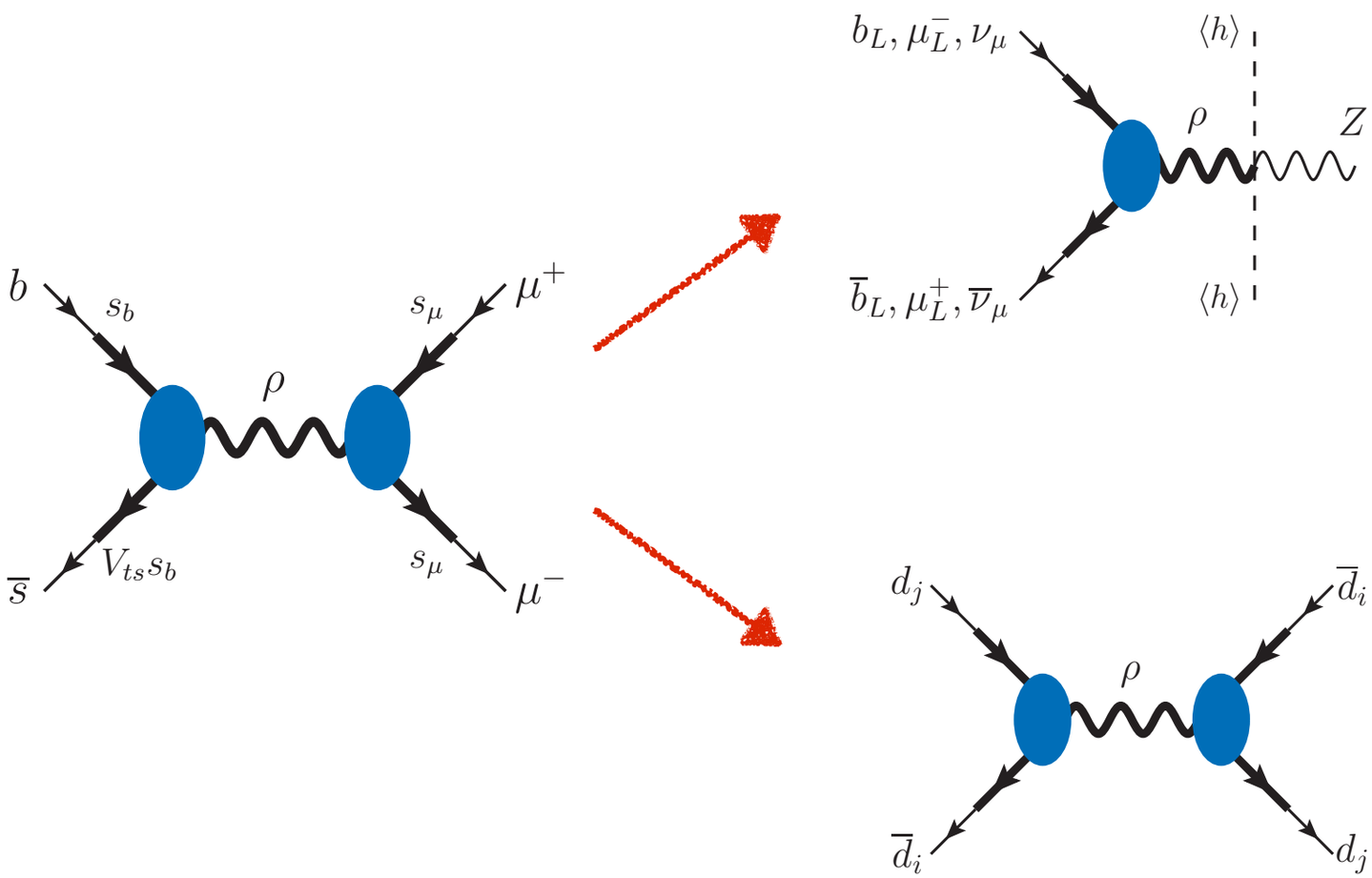
- Induced after EWSB by mixing:
  - Z boson with vector states
  - elem. fermions with partners

- coupling to leptons mediated by Z current:

  → **lepton flavor universal**: do not modify R_K and R_{K^*}

Implications for flavour and EW physics

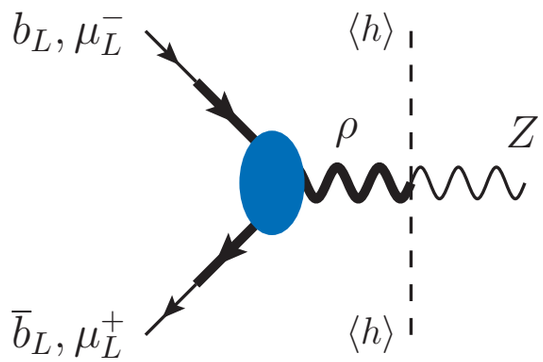
The vector resonances give rise to other unavoidable effects



distortion of the Z and W couplings

$\Delta F = 2$ transitions

Z couplings to μ and b



The distortion of the Z couplings can lead to strong constraints

$$\frac{\delta g_{Z f_L f_L}}{g^{\rm SM}_{Z f_L f_L}} \sim s^2_{f_L} \frac{g_\rho^2}{m_\rho^2} \frac{v^2}{2} \sim 2 \times 10^{-3} \left(\frac{s_{f_L}}{0.3}\right)^2 \left(\frac{1\ \text{TeV}}{m_\rho/g_\rho}\right)^2$$

from the current constraints one finds an upper bound on the amount of b and μ compositeness

$$\frac{\delta g_{Z f_L f_L}}{g^{\rm SM}_{Z f_L f_L}} \lesssim few \times 10^{-3} \longrightarrow s_{b_L}, s_{\mu_L} \lesssim 0.3$$

➡ constraints close to values needed to explain B anomalies

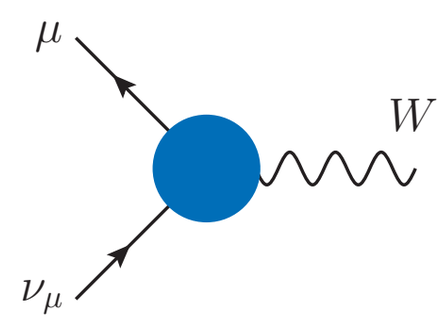
$$\Delta C^\mu_{9,10} \sim -0.4 \left(\frac{m_\rho/g_\rho}{1\ \text{TeV}}\right)^2 \left(\frac{\delta g_{Z b_L b_L}/g^{\rm SM}_{Z b_L b_L}}{10^{-3}}\right) \left(\frac{\delta g_{Z \mu_L \mu_L}/g^{\rm SM}_{Z \mu_L \mu_L}}{5 \times 10^{-3}}\right)$$

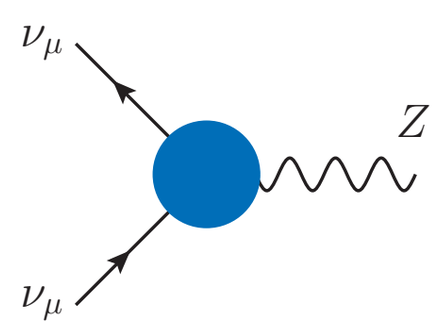
More on the Z and W couplings

Deviations in the Z couplings to μ and b can be avoided in models with custodial symmetry by imposing a **P_{LR} invariance**

... but the couplings involving ν_μ can not be protected!

$$\frac{\delta g_{W\mu\nu_\mu}}{g^{\rm SM}_{W\mu\nu_\mu}} \sim \frac{\delta g_{Z\nu_\mu\nu_\mu}}{g^{\rm SM}_{Z\nu_\mu\nu_\mu}} \sim 2\times 10^{-3}\left(\frac{s_{\mu_L}}{0.3}\right)^2\left(\frac{1\ \text{TeV}}{m_\rho/g_\rho}\right)^2$$

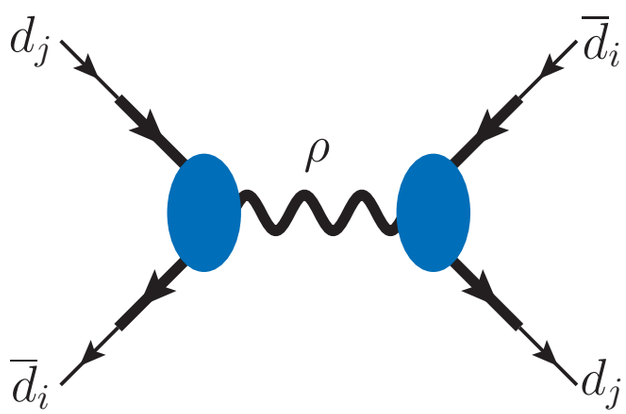




- ✦ Tested with very good accuracy $(few \times 10^{-3})$
  - muon decay (extraction of Fermi constant)
  - Z boson width

➡ deviations close to the experimental bounds if we want to explain B anomalies

$\Delta F = 2$ transitions



Vector resonances also mediate $\Delta F = 2$ effective interactions

$$\mathcal{O}^{LL}_{\Delta F=2} \sim s^4_{b_L}\left(\frac{g_\rho}{m_\rho}\right)^2 (V^*_{3i}V_{3j})^2(\bar{d}_{iL}\gamma^\mu d_{jL})^2$$

$$\simeq \frac{1}{(10\ \mathrm{TeV})^2}\left(\frac{s_{b_L}}{0.3}\right)^4\left(\frac{1\ \mathrm{TeV}}{m_\rho/g_\rho}\right)^2 (V^*_{3i}V_{3j})^2(\bar{d}_{iL}\gamma^\mu d_{jL})^2$$

- current flavor bounds imply the constraint

$$s^4_{b_L}\left(\frac{g_\rho}{m_\rho}\right)^2 \lesssim \frac{1}{(5\ \mathrm{TeV})^2} \quad \longrightarrow \quad s_{b_L} \lesssim 0.4$$

➡ constraints close to values needed to explain B anomalies

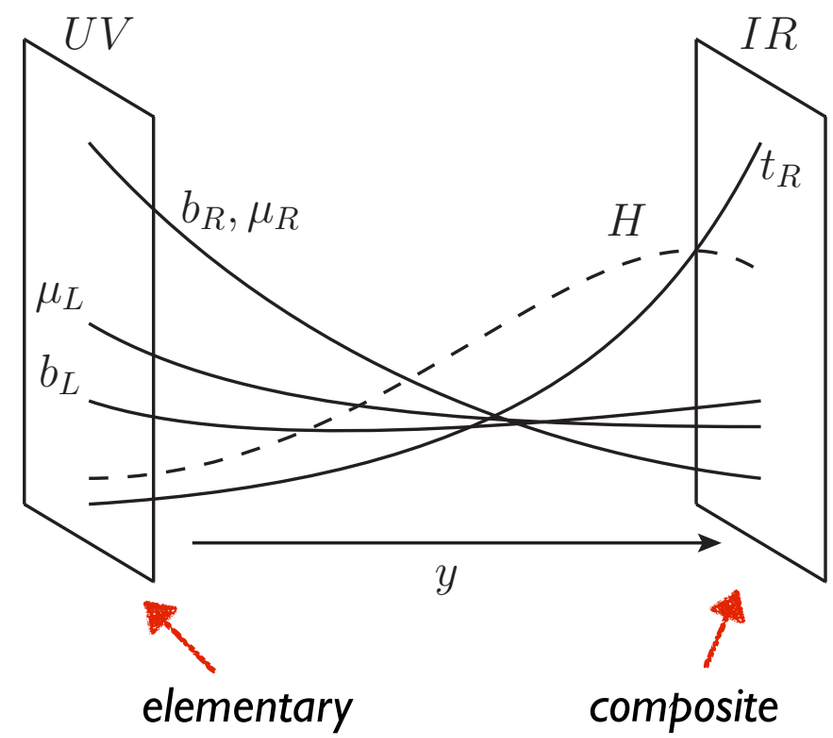
An explicit model

B-anomalies from RS

A modified RS scenario

An explicit realization can be obtained in an extra-dimensional scenario a la Randall-Sundrum

$$ds^2 = e^{-2A(y)}\eta_{\mu\nu}dx^\mu dx^\nu + dy^2$$



- **Higgs** is a composite state
  → localized towards the IR brane

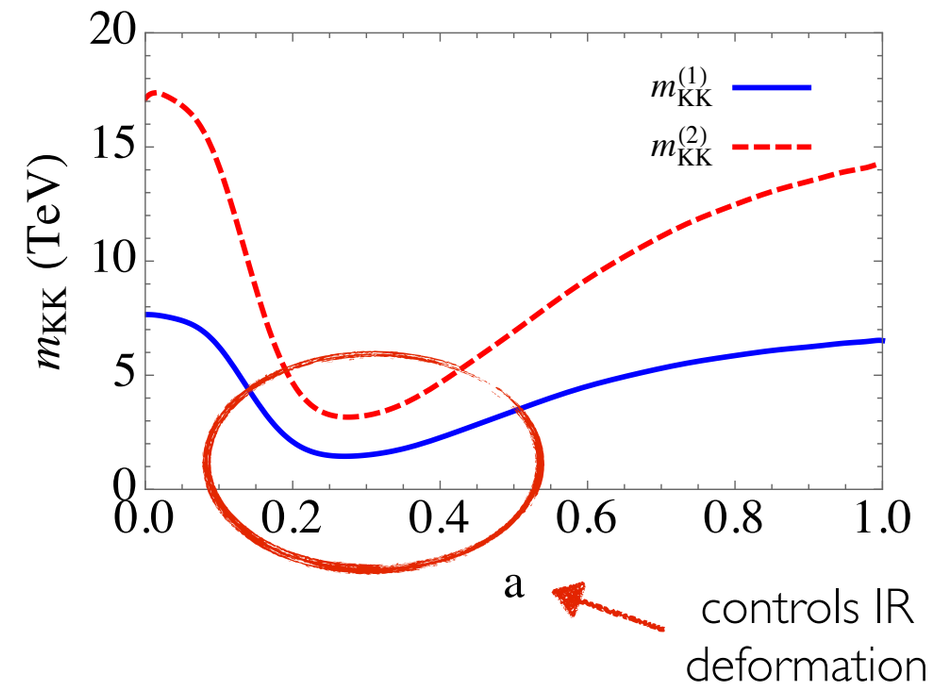
- **fermion compositeness** controlled by the bulk mass c_f
  - almost elementary $c_f > 0.5$ (eg. 1st gen., b_R, μ_R)
    (UV localized)
  - sizeable compositeness $c_f \lesssim 0.5$ (eg. top, b_L, μ_L)
    (IR localized)

EW bounds

EW correction to oblique S,T parameters under control by small deformation of the metric close to IR

typical mass of the **lightest gauge KK's**

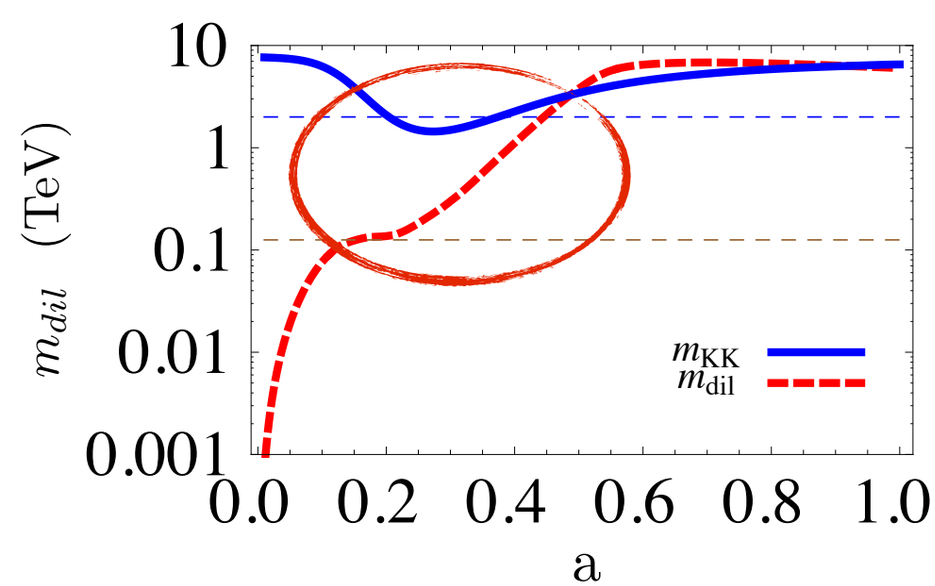
$$m_\rho^{(1)} \sim 2 - 3 \text{ TeV}$$



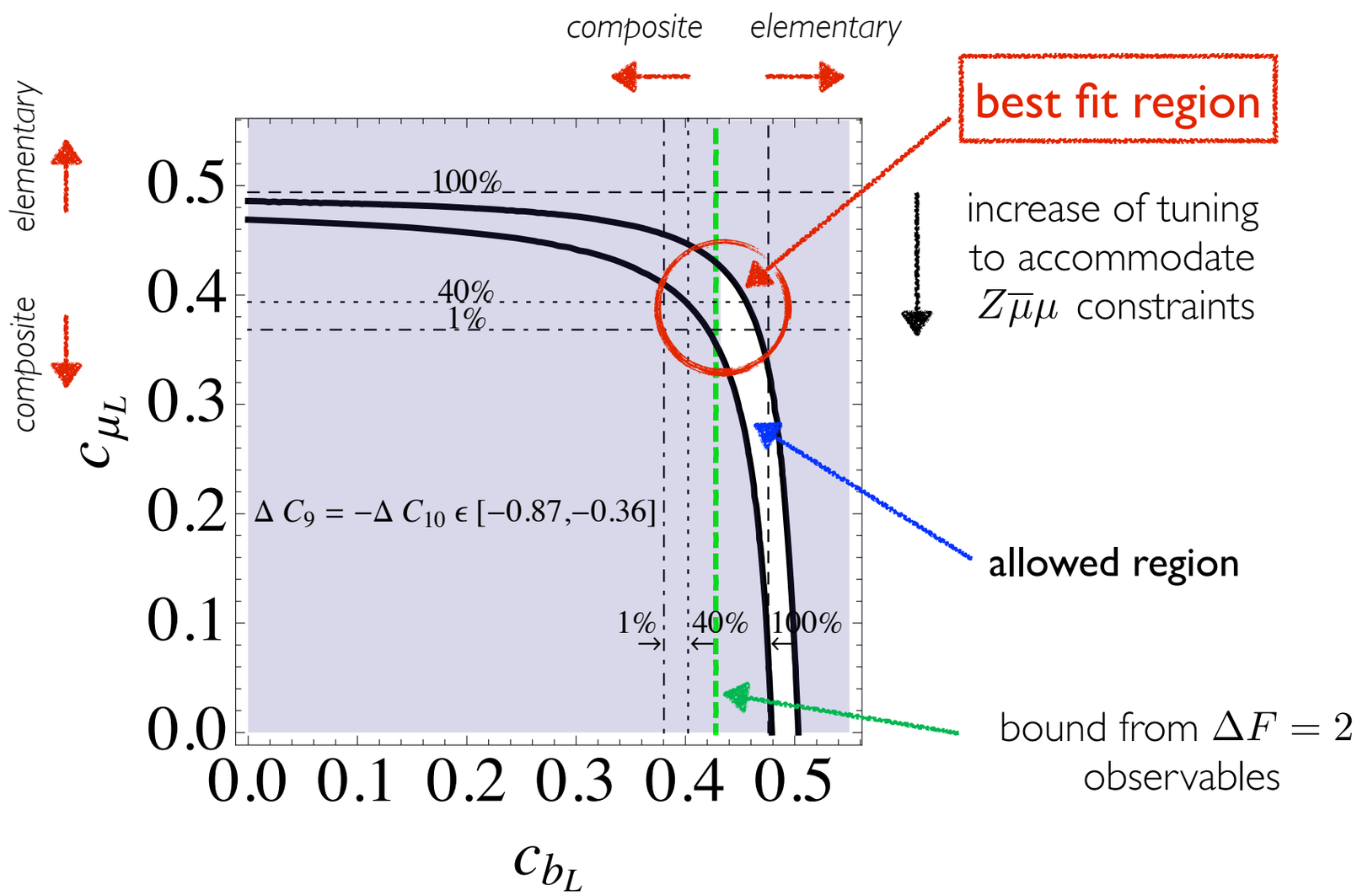
a **light dilaton** could also be present

$$m_{dil} \sim 0.1 - 3 \text{ TeV}$$

➡ still allowed due to reduced couplings to SM



Reproducing the B anomalies



- the B anomalies can be easily reproduced
- compelling scenario with b and μ localization fixed
  - correlated effects in $\Delta F = 2$ transitions, Z and W couplings close to experimental bounds

Additional signatures

- **Heavy gluon KK modes:** expected to have a mass comparable with the EW gauge resonances
  - copiously produced at LHC: current bounds $m_{KK} \gtrsim 2\ \mathrm{TeV}$
  - natural region of parameter space testable soon

- **EW gauge KK modes:** enhanced couplings to muons
  - harder to produce, possibly visible if light quarks are not too elementary

- **Fermionic KK modes**
  - typical mass in the few TeV region
  - quark KK partners testable in future LHC runs

Conclusions

Conclusions

Anomalies in B physics seem to follow a coherent pattern, possibly pointing to violation of lepton universality

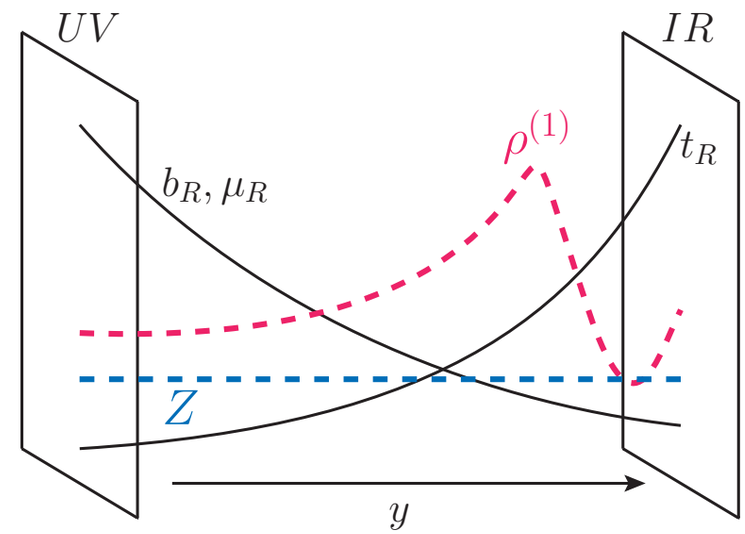
Models with a **composite Higgs** and new strong dynamics can explain the anomalies and link them to the **Naturalness Problem**

- ✦ generic features:
  - sizeable **muon** and **bottom compositeness**
  - related **deviations** in Z and W couplings and $\Delta F = 2$ transitions
  - **heavy resonances at the TeV scale** testable at the LHC
    (heavy gluons, heavy vectors, fermionic partners)
- ✦ flavor symmetries needed in lepton sector…
- ✦ predictive explicit implementations in extra-dimensions

Backup

Breaking lepton universality

SM gauge fields (KK zero modes) have flat profiles



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flavor-universal couplings
(up to small corrections after EWSB)

Massive KK modes have a non-trivial profile: IR localized

↓

stronger couplings with composite fields:
universality violation